Report from Dagstuhl Seminar 13512

Social Issues in Computational Transportation Science

Edited by

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Abstract

The Dagstuhl Seminar, "Social Issues in Computational Transportation Science" (13512) took place from 15 to 19 December 2103, attracting 27 participants active in a wide range of academic, commercial, and public sector areas. CTS is an emerging discipline that combines advances in computer science and engineering with the modeling, planning, social, and economic aspects of transportation in order to improve the safety, mobility, and sustainability of transportation systems. The aim of this seminar was to focus on the social computing aspects of CTS, including such areas as social networks and crowd-sourcing for transportation, as well as the integration of persuasive technologies and behavioral economics in social computing. In their time at the workshop, participants discussed and debated these and other topics, as shown in the workshop's summary report.

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1 Executive Summary

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The Dagstuhl Seminar "Social Issues in Computational Transportation Science" (13512) brought together researchers working in various areas contributing to Computational Transportation Science (CTS). CTS is an emerging discipline that combines computer science and engineering with the modeling, planning, social, and economic aspects of transportation. It is the discipline behind intelligent transportation systems (ITS), i.e., emerging from the convergence of ICT and transportation. The discipline studies how to improve the safety, mobility, and sustainability of transportation systems by taking advantage of information technologies and ubiquitous computing.

After a first Dagstuhl Seminar on CTS in 2010 (10121), in this seminar we focused on the social computing aspect of CTS, reflecting on the potential of many recent developments in transportation, such as social networks, crowdsourcing of spatial data, persuasive technologies, and behavioural economics in social computing.

In fact, the seminar (which was a day shorter because of Christmas) consisted of three parts: a number of tutorials and short talks, a competition for the best application challenge in CTS, and a joint sketch of an introductory course on CTS. An excursion to the Christmas Market in Trier rounded up the week.

The CTS application challenge was inspired by above mentioned social aspects, such as incentives to change travel behaviour, data integration / analytics required to feed these incentives, multimodal integrated door-to-door travel, autonomous vehicles, automated crowdsourcing for travel statistics, or smart solutions for the parking problem. In case you are curious which team won the best proposal award, their proposal is online[1].

The sketch of an introductory course on CTS clearly profited from the broad variety of expertise at the seminar. Everybody was learning from the sketches of modules contributed by others, to a degree that we all wished we could take this course in full length.

Overall, this report collects material that wants to be taken into practice. We hope that we inspire teams all over the world to contribute ICT expertise for more sustainable mobility choices, and perhaps add to the development of curricula in this area.

[1] https://sites.google.com/site/karmobility/home

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3 Overview of Talks

3.1 Informed Rural Passenger

Caitlin Cottrill (University of Aberdeen, GB)

Joint work of Edwards, Pete; Nelson, John; Sripada, Yaji; Pan, Jeff; Cottrill, Caitlin; Beecroft, Mark; Corsar, David; Baillie, Christopher; Markovic, Milan; Papangelis, Konstantinos
Main reference N. R. Velaga, M. Beecroft, J. D. Nelson, D. Corsar, P. Edwards, "Transport poverty meets the digital divide: accessibility and connectivity in rural communities," Journal of Transport Geography, Vol. 21, March 2012, pp. 102–112, 2012.
URL http://dx.doi.org/10.1016/j.jtrangeo.2011.12.005

The Informed Rural Passenger project aims to address problems of inadequate information sources for public transport in rural areas via the use of a smartphone app ('GetThere Bus') and crowdsourced information. Our research indicates that passengers desire real-time information that is accurate, timely, and personalised, and informs travellers about potential disruptions and transport alternatives. To address these needs via the app, we have worked to develop an ecosystem whereby travellers may both send and receive information on bus schedules and delays, with visual representations of information quality and provenance. Our initial research has resulted in a demonstration app and pilot test, which indicated that more work was needed to address alternate methods of information dissemination in rural areas. This finding has informed our current and planned research on the use of text messages for information provision, as well as more systematic use of social media.

3.2 Urban Informatics at NICTA

Glenn Geers (NICTA – Kensington, AU)

Joint work of Geers, Glenn; Cai, Chen; Economou. Dean; Liu, Wei; Tyler, Paul

In the talk I will give a brief overview of some work that is currently being carried out at NICTA. It asks more questions than it answers.

1. Co-operative Intelligent Transport Initiative This project aims to build the world's first heavy goods vehicle specific V2X test-bed on a 42 km route located south of the City of Sydney, Australia. Phase 1 is due for completion mid-2014 and will comprise thirty instrumented trucks, three connected signalised junctions and several portable roadside DSRC systems. An additional aim is to make as much data available to the research community as possible. The project is an initiative of the Centre for Road Safety which is part of Transport for New South Wales.
   Phase 2 of the CITI Project (subject to funding) will add various road-side sensors and integrate light vehicles and pedestrians into the connected system. It is hoped to run the site as a managed open research facility.
2. Data Driven Traffic Modelling This project is developing methods of applying machine learning to the road network. Is it possible to predict the location of potential black spots from traffic data? Can incident duration be predicted and reduced? How can data driven models be linked to more traditional micro- or meso-scale simulations?

There are challenging issues for machine learning: how can new data types be added without having to completely re-learn the model (transfer learning). How can the large spatial and temporal scale issues (intersection to city-wide; seconds to years) be handled?

3. Computable Liveability Every year many organisations produce and publish 'Liveability' Indices for cities around the world. However, there is no agreed definition of liveability and therefore no way to compare indices produced by different organisations. Most measures rate Western cities highly. Why?
   Is it possible to go from survey data to physical data? Does building a new hospital compensate for increasing traffic on the roads? Can we derive a personal liveability index based on measured data?

3.3 Towards Intelligent and Generic LBS for Drivers and Mobile Users

Sergio Ilarri (University of Zaragoza, ES)

In this talk I will focus on Location-Based Services (LBS) for hybrid networks composed of both vehicles and mobile users. The motivation is the interest of studying data management solutions that take into account a generic environment where different types of moving objects share different types of data and possibly using different communication technologies (ad hoc wireless communications forming a pure mobile P2P network, hybrid mobile P2P network with support infrastructure nodes, wide-area communications like 3G, etc.).

I will start by summarizing some data management challenges for vehicular networks, related to the exchange of events (efficient and effective content-based data dissemination for push-based data access), query processing (pull-based data access by using query dissemination or mobile agent technology), data item relevance evaluation, management of information about scarce resources (like available parking spaces or charge stations for electric vehicles), semantic data management, automatic knowledge extraction from the data items, multimedia data management, incentives, and trust. Then, I will show some use cases that exploit sensors embedded in moving objects to obtain interesting information (environment monitoring and multimedia data). Afterwards, I will emphasize the role that semantic technologies can play in this context and the benefits that they can provide as facilitators for the development of intelligent and generic LBS. Finally, I will present as an example the basics of our current prototype SHERLOCK (System for Heterogeneous mobilE Requests by Leveraging Ontological and Contextual Knowledge), which exploits shared knowledge about different types of objects and services (encoded in ontologies) to offer interesting services and information to mobile users.

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3.4 Issues in Agent-based Route Choice Models

Franziska Klügl (Örebro University, SE)

Agent-based simulation forms one of the most prominent microscopic simulation paradigms. It is applied basically in all areas in which actors situated and interacting in an environment are to be modeled and analyzed. It is best characterized as "generative" simulation as the overall system properties and behavior are not merely described, but generated from lower level agent behavior and interaction. Agent-based simulation promises to solve many problematic issues of modeling in general, ranging from the possibility to formulate heterogeneity on various levels to integration of individual-level adaptation and population-level evolution that allows the simulation of self-organization and generative analysis of emergent phenomena.

Meanwhile, agent-based simulation plays an important role in traffic simulation: activity-based approaches for travel demand modeling as well as advance routing and mobility simulations (for a review see [1]). Modeling and simulation of route choice plays hereby a prominent role, as the problem can be mapped to gametheoretic scenarios such as the El-Farol Bar Problem or Minority Games. These scenarios can even be approached by experimentation for analyzing human decision making [2]: Classically, there are two options (to go to the bar or to stay at home, go on highway or country road, stay on route or change to alternative) between which each agent has to choose. The agents choosing the less crowded alternative receive the higher reward and based on that adapt their decision making. Over the years, many studies also with related problems (e.g. the Braess Paradox) have been conducted, mainly focusing on the question whether and how information on previous choices or predictions of load influence the overall outcome of equilibriums (for example [4]). These scenarios were intended to analyze human decision making in traffic situation, so an attempt has been made to scale them to real-world networks [3]. The main results of these experiments also involving information given at different locations in the network were that the scaling up to more realistic problems is not trivial with respect to:

- Generation of options to choose: It is hard to generate a set of independent routes. This is a well-known problem in discrete choice modeling.
- Integration of feedback. If there are no full routes as options, the agents cannot assign feedback in form of overall travel time to routes, rather than to links. This feedback can be used to build a belief set of traveltimes on links that can be used in shortest path algorithm. So, the general decision making needs to be adapted to more complex decision making instead of just selecting between options.

Nevertheless, these experiments show that one can analyze the spontaneous redistribution of traffic load based on individual decision making available while moving through the network. Yet, for what form of simulation objectives such intermediate models between the highly abstract game-theoretic approaches and full detail simulations containing daily plans with mode- and route choice informing detailed mobility simulations, is not yet clear. If it is so difficult to map the gametheoretic scenarios to real world situation, their explanatory value needs to be discussed.

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3.5 Stream Processing and Crowdsourcing for Urban Traffic Management

Thomas Liebig (TU Dortmund, DE)

Joint work of Artikis, Alexander; Bockermann, Christian; Boutsis, Ioannis; Gal, Avigdor; Gunopulos, Dimitrios; Kalogeraki, Vana; Kinane, Dermot; Liebig, Thomas; Mannor, Shie; Marecek, Jakub; Morik, Katharina; Piatkowski, Nico; Schnitzler, Francois; Weidlich, Matthias
URL http://www.insight-ict.eu/

The recent development of innovative technologies related to mobile computing combined with smart city infrastructures is generating massive, heterogeneous data and creating the opportunities for novel applications. In traffic monitoring, the data sources include traditional ones (sensors) as well as novel ones such as micro- blogging applications like Twitter; these provide a new stream of textual information that can be utilized to capture events, or allow citizens to constantly interact using mobile sensors.

The long term goal of the related INSIGHT project is to enable traffic managers to detect with a high degree of certainty unusual events throughout the network. We report on the design of a monitoring system that takes input from a set of traffic sensors, both static (intersection located, traffic flow and density monitoring sensors) and mobile (GPS equipped public transportation buses). We explore the advantages of having such an infrastructure available and address its limitations.

We give an overview of the system developed to address the veracity, velocity and sparsity problems of urban traffic management. The system has been developed as part of the European FP7 project INSIGHT under grant 318225. The general architecture is given in [1]. We describe the input and output of the system, the individual components that perform the data analysis, and the stream processing connecting middleware.

We base the stream processing based on the Streams framework [2]. Streams provides a XML-based language for the description of data flow graphs that work on sequences of data items which are represented by sets of key-value pairs, i.e. event attributes and their values. The actual processing logic, i.e. the nodes of the data flow graph, is realised by processes that comprise a sequence of processors. Processes take a stream or a queue as input and processors, in turn, apply a function to the data items in a stream. All these concepts are implemented in Java, so that adding customized processors is realised by implementing the respective interfaces of the Streams API. In addition, Streams allows for the specification of services, i.e. sets of functions that are accessible throughout the stream processing application.

We extend and apply the system for individual trip planning that incorporates future traffic hazards in routing [3]. Future traffic conditions are computed by a Spatio-Temporal Random Field [6] based on a stream of sensor readings. In addition, our approach estimates traffic flow in areas with low sensor coverage using a Gaussian Process Regression [4,5]. The conditioning of spatial regression on intermediate predictions of a discrete probabilistic graphical model allows to incorporate historical data, streamed online data and a rich dependency structure at the same time. We demonstrate the system and test model assumptions with a real-world use-case from Dublin city, Ireland.

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3.6 Social networks and activity/travel behaviour

Nicole Ronald (The University of Melbourne, AU)

An overview of research into social networks and activity/travel behaviour was presented. The main areas discussed were the influence of social networks on travel behaviour, how social network data has been collected [4], how data can be used to synthesise relationships in a population [1], and how models of social activities and influence can be developed [2,3,5]. Parallels to the field of computational transportation science were also discussed.

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3.7 Intelligent Parking Assistant

Bo Xu (Argonne National Laboratory, US)

Joint work of Xu, Bo; Wolfson, Ouri

Finding parking is a major hassle for drivers in urban areas. Studies conducted in 11 major cities reveal that the average time searching for curbside parking was 8.1 minutes and cruising for these parking slots accounted for 30% of the traffic congestion in those cities. Each parking slot generates at least 1,825 vehicle miles traveled (VMT) per year. Thus, in a city like Chicago with over 35,000 curbside slots, cruising for parking generates 63 million VMT. This wastes over 3.1 million gallons of gasoline and produces over 48,000 tons of CO2 emissions.

Intelligent Parking Assistant (IPA), currently being developed in UIC, is a software application that runs on smartphones and car navigation systems, and guides a driver to a parking slot similarly to a Car Navigation System that guides her to the destination.

IPA consists of two subsystems, a Parking Detector (PD) and a Parking Navigator (PN). PD automatically estimates the average number of parking slots on city blocks. It uses a novel method that builds a historical profile of parking availability on each city block, and combines it with real-time information from smartphones. In contrast, existing solutions that detect parking availability either use specialized expensive sensors, or require manual input. PN guides the driver through a path where she is most likely to compete effectively for parking. PN uses a novel Gravity-based Parking Algorithm, developed using game-theory to address the competitive aspect

4 Introductory CTS Course

Seminar participants, in groups, developed modules for an introductory level course in CTS as it could be offered in the third or fourth year of a computer science or engineering program. Each module was to contain material of core knowledge for one to two class lectures, with reading lists added as appropriate. The following nine themes were identified and are further described below:

1. Knowledge discovery
2. Route planning
3. Optimization
4. Visualization and visual analytics
5. Simulation and prediction analysis
6. Stream processing
7. Data modelling
8. Incentive design
9. Human factors

4.1 Knowledge Discovery

Bo Xu, Sergio Di Martino, and Franziska Klügl

The Knowledge Discovery topic would be designed as follows:

Subsections

- Introduction: Available Data Sources, Typical Questions, General Knowledge Discovery Process
- Methods: Problem classes; Method categories and Clustering in more detail
- Tools: WEKA

Learning Objectives

- Overview of knowledge discovery process with special emphasis on spatial data
- Students can evaluate which method category is suitable for which problem
- Students are enabled to perform simple knowledge discovery tasks

A potential homework assignment would be to use WEKA with self-programmed similarity metrics (requires JAVA) for k-means clustering on data such as that from SFpark[2].

[2] http://sfpark.org/

4.2 Route Planning

Harvey Miller, Stefan Funke, and Peter Sanders

The recommended Route Planning course would be structured as follows:

Recommended Prerequisites
- graphs, graph representations
- Dijkstra's algorithm

Class subsections
- Modeling: route planning on road networks
- Basic algorithms
- Speed-Up techniques
- Modeling: route planning in PT networks
- NP-hard route planning variants (this will link to optimization topics)

Learning objectives
- ability to model basic route planning tasks
- being able to solve them using basic algorithms
- awareness of existing speedup-techniques
- intuition for complexity of different route planning tasks

4.3 Optimization in the Context of CTS

Jan Fabian Ehmke

Joint work of Ehmke, Jan Fabian; Fitzpatrick, Rob; Storandt, Sabine

Prerequisites
Ideally, students should be familiar with complexities and (linear) optimization, as of course those topics can not be covered in a single course. Nevertheless, we try to motivate and explain optimization in the CTS context relying on prior knowledge as little as possible.

Learning Objectives
The overall goal is to show how optimization can be useful in the context of CTS. For that purpose, a basic understanding of mathematical modelling and problem solving should be conveyed. Moreover, the difference between exact optimization and the usage of heuristics should become clear. To motivate these approaches, different levels of complexity need to be explained, most convenient based on some well-known optimization problem (e.g. Travelling Salesman). Finally, the incorporation of real-world features and constraints should be sketched.

Structure of the Lecture
We present a template structure with the steps we consider important to introduce students to CTS related optimization. We accompany each step with a concrete suggestion, but we want to emphasize that depending on the expertise and interest of the lecturer the discussed problems and examples can easily be exchanged.

1. **Motivating example problem.** This problem should be transportation related but simple and easy to explain at the same time, like e.g. vehicle scheduling, facility location or the vehicle routing problem (VRP). We focus on the latter in the following. Based on the motivating example it should be explained what an objective is in general, what the concrete objective for the example is and what other common objectives are relevant in CTS.
2. **Methods for Solving Optimization Problems.** Now we want to give some insights in solution methods. We concentrate on the motivation example for this purpose. We even suggest to use the most simplified version of this example for consideration, for VRP we suggest to use the Travelling Salesman Problem (TSP). We concentrate on three ways to solve optimization problems:
   - Naive, i.e., for TSP compute all possible permutations. We would illustrate the impracticability of this approach with a runtime estimation for a reasonably sized TSP instance on some machine. Also the theoretical runtime formula explaining this combinatorial explosion should be given along. This should arise the question how to handle such computational complex problems in a better way.
   - Mathematical Modelling is a logical next step. Here the objective should be formulated as a function and students should get a glimpse on how constraints can be realized. To show the usefulness of mathematical models, the existence of solvers should be mentioned, maybe showing a small example of the TSP formulation for a specific solver and the received result (along with the runtime).
   - Heuristics should then be introduced as a remedy for retrieving solutions also for larger instances which cannot be solved exactly in a reasonable time span. Some simple heuristics for the chosen example should be explained, e.g. for TSP the nearest neighbor greedy algorithm, the insertion approach and the savings technique are recommendable. It should be emphasized that we compromise solution quality for the sake of run time with these approaches.
3. **Modelling Problems More Realistically.** Now the way from the abstract optimization problem back to real-world problem should be found. This can be done by enumerating constraints one has to deal with in practice. For our VRP example, this could include time windows, time-dependent travel times along with traffic congestions, varying capacities of the vehicles and possible drivers' or driving restrictions. Normally, there are ways to extend the mathematical model in order to incorporate such constraints, but, of course, it gets more complex in that way. Also a remark on the integrability of real-world data should be made here (reference to the lecture on 'Data Modelling'). Then the extension of a heuristic for a real-world constraint can show the power of such techniques, e.g. the extension of the insertion heuristic for TSP taking time windows into account. Again, a look on the complexity (here factorial versus quadratical) and solution quality makes sense.
4. **Outlook.** As obviously in a single course the huge world of optimization can not be covered, we finally give an overview of exemplary extensions that consider time-space dimensions important in the CTS context, like
   - static versus dynamic problems
   - several types of heuristics (approximation algorithms, metaheuristics, . . .)
   - other solution techniques (dynamic programming, local search, . . .)
   - linear versus non-linear optimization

Useful Resources
- Online OpenStreetMap TSP[3]
- Online GoogleMaps TSP[4]
- Excel VRP Solver (Open Source)[5]
- Vehicle Routing Game[6]
- Online course on Discrete Optimization (van Hentenryck)[7]

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4.4 Visualisation and Visual Analytics

Walied Othman

In this course we will convince the students of the need for visualization and visual analytics. There are multiple examples, even dating back to two centuries ago, that the eye can absorb a lot of information when presented visually, i.e., a train schedule from 1885 between Paris and Lyon. Not only is visualization important in conveying information, it is a key player in knowledge discovery via visual analytics. In this course we will show that visual analytics is a back-and-forth process between visually inspecting data, visually selecting an area of interest and applying a transformation if necessary, from which knowledge can be generated and visualized. This is a creative process, and the best way to approach this is to provide the students with a plethora of examples from which they can draw inspiration from. The class will go through a hands-on process of visual analytics on an example data set and receive a similar take-home assignment. In the following class, students get a chance to present their work to each other and validate their visualizations with, for example, a survey.

[3] http://algohol01.informatik.uni-stuttgart.de/
[4] http://www.gebweb.net/optimap/
[5] http://verolog.deis.unibo.it/news-events/general-news/vrp-spreadsheet-solver
[6] http://game.costtoserve.net/
[7] https://www.coursera.org/course/optimization

4.5 Simulations in transportation science

Francesco Ciari, Nicole Ronald, and Seng Wai Loke

Computer power and availability of data have grown dramatically in recent years making even data and computational intensive simulations a viable planning option. This lecture offers students an overview of simulation techniques as applied to transportation science. The main goal of this lecture is to provide students with some background on the topic and an understanding of the situations in which simulations can be appropriate transport planning tools. The students will be given the opportunity to "play around" with some simulation tools in order to get a direct experience of pros and cons of this type of technique. Below, a structure for a 90-minute lecture is provided.

Motivation
- The application of computational tools to assist in making decisions about planning design and operations of transportation systems
- Many problems cannot be explored directly but need to be simulated

Learning Objectives
- Be able to select the appropriate simulation for a given problem
- Understand and apply simulation tools to solve transportation problems
- Being able to interpret and analyze the outputs

Cellula Automata (CA) + Traffic Microsimulation
- CA Model
  - Discrete time and space (grid-based)
- Traffic Microsimulation
  - Discrete time, continuous space
  - Examples (Videos)
  - Topics include car following algorithms and applications

Agent-based simulations
- Based on MATSim
- Discrete time, queue-based
- Topics include overall process, utility functions, and applications
- Example (Videos)
- Can also make use of existing teaching materials (see Readings)

Scope and Limitations
- For each approach:
  - What is the scope
  - What are their inherent limitations
  - Which kind of output
  - How they do compare

Assignment
- Students get a small scenario, some options to investigate policies and are assigned the appropriate model (i.e. MATSim or Sumo) to investigate it
- Students should implement the given policy scenario, run the simulation and draw conclusions based on the analysis of the results

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4.6 Stream Processing in the Context of CTS

Sergio Ilarri, Thomas Liebig, Steve Liang, and Glenn Geers

The recent development of innovative technologies related to mobile computing combined with smart city infrastructures is generating massive, heterogeneous data and creating opportunities for novel applications in transportational computation science. The heterogeneous data sources provide streams of information that can be used to create smart cities. The knowledge on stream analysis is thus crucial and requires collaboration of people working in logistics, city planning, transportation engineering and data science.

We provide a list of materials for a course on stream processing for computational transportation science. The objectives of the course are:

- Motivate data stream and event processing, its model and challenges.
- Acquire basic knowledge about data stream processing systems.
- Understand and analyze their application in the transportation domain.

Since the subject is large and comprises many aspects, we propose that the course should start with an examplary application which is familiar to the audience. The chosen example expands through the whole course and illustrates a particular aspect in each section.

Topics to be covered

1. Introduction
   - Literature
     - Models and Issues in Data Stream Systems [4, 13]
     - Data Stream Management: [21]
     - Transportation and Data Streams: [40]
     - Smart Cities and Heterogeneous Data Streams: [36]
   - Event stream examples in transportation

    - linear ordered sequence events, e.g., bus arrival times
    - an event cloud consists of many event streams, e.g., traveler arrival time and bus arrival time at interchange
    - moving car trajectories
  - Challenges in stream processing
  - OGC standards and interfaces [15]
2. Data Stream Management Systems (DSMSs)
  - Lambda Architecture for Stream Processing [31]
  - Speed Layer: STREAM [1], Aurora [6], Borealis [39], Storm [38], streams [9], S4 [32], Kafka [19]
  - Batch Layer: MapReduce [14], Hadoop [41], Spark [42], Disco [16]
  - Distributed NoSQL Databases: Cassandra [24], MongoDB [35]
3. Data Analysis
  - Query Languages: Esper [30], NiagaraCQ [10], and others [5, 22, 25]
  - Complex Event Processing (CEP): [7, 12, 27]
  - Learning: streams [9], Mahout [33], MOA [8]
  - Distributed streams: [37]
  - Sketches: [11, 18] privacy with sketches [23]
4. Example applications in the transportation domain: [2, 3, 17, 20, 26, 28, 29, 34, 43]

Possible home assignment

- Study a certain DSMS and summarize its features in a report.

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4.7 Data Modeling

Dirk Christian Mattfeld, Patrick Laube, and Monika Sester

The recommended Data Modeling course would be structured as follows:

Class subsections

- The term 'model', definition and properties (mapping, abstraction and reduction, goal orientation)
- Three levels for CTS tasks: sensing, control, and planning
- Conceptual data models for movement traces and movement spaces
  - conceptual data models for spatial information: entities and fields
  - graphs, networks
  - trajectories

Learning objectives

- The students can give a concise definition of the concept 'model', and can list its key properties.
- The students can assign given CTS tasks to the three task levels (1) sensing, (2) control, and (3) planning, and can name methods suitable for the given tasks.
- The students acquire a workbench of basic conceptual data models required for CTS (including conceptual data models for spatial information, ...).
- The students understand that depending on the task at hand, different data models are required.

4.8 Incentive Design

Alexandros Labrinidis and Ouri Wolfson

The recommended Incentive Design course would be structured as follows:

Class subsections

- introductory microeconomics
- game theory/mechanism design
- examples of incentive schemes in transportation

Learning objectives

- Understand Nash equilibrium/Pareto efficiency – personal versus global optima
- Understand law of supply and demand / differential pricing
- Understand mechanism design, taking into account "attacks"
- Review uses of incentives, with regards to transportation/mobility
- Understand types of incentives

Sample assignments

- Simulate introduction of HOV lane
- Walk-or-wait at stalled elevator

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4.9 Human Factors

Stephan Winter, Sabine Timpf, and Caitlin Cottrill

The recommended Human Factors course would be structured as follows:

Class subsections
- information availability and usability
- relevance theory
- activity theory
- spatial cognition
- socio-technical systems theory
- user satusfaction/usability testing
- incentives (see above)

Learning objectives
- Students will understand that people are at the centre of transport. People's transport choices determine traffic, and information *about* their choices influences their choices, along with the trip purpose and existing constraints (context).
- Students will experience and evaluate the direct and indirect costs caused by the particular design of transport information (systems). The direct costs are those of finding information, and the indirect costs are those that follow from not using systems that are inconvenient to use and using the private car instead.

Potential assignments
- Urban trail: The student will design a route description for a route passing five landmark features in the city, for various types of people. Compare your descriptions by chosen references and the spatial granularity of each of them.
- Unfamiliar mode: The student should come to the university with a mode different from that usually taken, and report about any usability issues (such as consistency of information, availability of information needed, etc.)
- Usability testing: The student will test two common tasks for mobile public transport planners (1. When does my next tram or bus depart? 2. I need to be at uni at 10am, so at what time do I need to be at my local tram/bus stop?)
- Can the student take the car navigation out of the car and use it for walking? Report issues.
- The student should plan his or her next holiday trip online and (a) observe the time needed, (b) report usability issues
- The student will use competing platforms for trip planning and compare them from a usability perspective.

Core concepts and theoretical bases

- Relevance theory [14]
  - Discuss along the patterns of a natural language dialog about start and destination point.
- Activity theory [5]
  - Discuss purpose of trip and implications on what information is relevant
  - Decision-support with mobile devices [13]
- Spatial Cognition
  - Mental spatial representations [1], schematic geometry [10]
  - Place, route and survey knowledge [11]
  - Structure of place and route descriptions [12]; [15] – include hierarchies of spatial (and temporal) granularities. Related: the challenge of transfers – not a node, but most complex part of a journey [4]
- Socio-technical systems theory [3]
  - Reliance on technology (e.g., navigation systems) relieves from forming mental spatial representations
  - Impacts of communication technology & associated temporal shifts on expectations of travel and travel planning [8]
  - Technological artifacts and their behaviour should conform to mental representations and models [9]

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5 Application Challenge

For the application challenge, participants competed in five groups to develop an original CTS application and a feasibility assessment. Presentations took place on the final afternoon of the seminar. The following abstracts were received.

5.1 karmobility

Alexandros Labrinidis, Patrick Laube, Steve Liang, Harvey J. Miller, Nicole Ronald, Stephan Winter, and Yang (Tara) Yue

karmobility[8] is an app designed to "increase your mobility karma" in the following ways:

Integration
- in the physical world, allow for the integration of multi-modal transportation options
- in the digital world, enable the integration of information from different sources and with other apps

Incentives
- in the physical world, encourage/reward behavior change
- in the digital world, encourage/reward participatory sensing

Karma
- in the physical world, people's good mobility choices have a positive impact on the environment and on public health
- in the digital world, people's good mobility choices are shared through social networks

[8] For more information, see https://sites.google.com/site/karmobility/home

5.2 HappyParking

Sergio di Martino, Rob Fitzpatrick, Sergio Ilarri, and Ouri Wolfson

There are estimations that indicate that about half of the vehicles on the move are searching for parking and that more than 40% of the total fuel consumption is spent while looking for an available parking space. This also contributes to significant urban traffic congestion. So, it would be interesting to have software tools that can help drivers to park easily.

For the application challenge, our group proposed a *HappyParking* application, which would offer some interesting benefits:

- It ackowledges the importance of considering parking in the context of a displacement between a source location and a target location. This implies that the final target location has to be considered when deciding an appropriate parking space. Moreover, the application can be integrated into existing GPS-based navigation applications.
- It considers multimodality, that is, that parking a car could be just a leg within a longer trip using different modes of transportation.
- It exploits real-time constraints (e.g., time-based parking restrictions).
- It can accommodate a variety of methods to capture information about available parking spaces (e.g., magnetic sensors on the parkings, crowdsourcing information provided by drivers releasing a spot, cars with different types of sensors able to detect free places, etc.).
- It supports different types of parking spaces: on-street parking, private parkings and garages, home parking available for rental during specific time periods, etc.

At a very high-level, the architecture supporting HappyParking is composed by four modules: the *Data Capture* module, the *Knowledge Discovery* module, the *Payment* module, and the *Incentives* module. The system is able to offer real-time parking recommendations. It computes the likelihood of parking at the estimated time of arrival: in a certain area, at certain times, and taking into account especial external real-time events (e.g., a big concert or music festival in the city). On the one hand, it offers recommendations that maximize the success probability, the user's satisfaction, and the global benefit for the community of drivers. On the other hand, those recommendations can minimize the distance to the final destination, the time to park, and the economic cost (fuel consumption). For this purpose, it learns the user preferences over time. Finally, for some types of parking spaces it is possible to book and pay for a guaranteed parking spot (e.g., based on a dynamic pricing schema).

In accordance to the above description, this kind of application would be useful for a variety of parties, such as drivers, garages, owners of private parking spaces, municipalities, car manufacturers, OEMs, ecologists and health systems. Nevertheless, the unique combination of features indicated requires additional research work to make such an application a reality.

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5.3 Ichibi – Everything you ever wanted in a multi-modal travel app

Caitlin Cottrill, Jan Fabian Ehmke, Glenn Geers, Franziska Klügl, and Sabine Timpf

Due to the multitude of travel options and prices, travel planning has become challenging nowadays. For the individual traveller, it is not easy to determine her best travel option. Existing travel apps offer only limited functionality for the consideration of complex traveller's preferences. Furthermore, there is hardly any en-route assistance, especially when it comes to multi-mode travel alternatives. Multi-mode travel options tend to be much more complex, though. En-route assistence would allow for real-time adapation and reaction to travel disruptions.

Ichibi provides pre-trip and en-route functionality and thus comprises everything you ever wanted in a multi-modal travel app. *Ichibi* is

1. Smart – learns the travelers' preferences and constraints,
2. Efficient – sets the travelers' preferences, selects the traveler's preferred alternative, books tickets, and it is
3. Timely – it reacts to travel disruptions and provides alternative travel options if needed.

Ichibi uses a middleware based approach that leverages available transport services and relevant data for travel planning by canonicalizing travel information into a consistent internal format that is able to be processed efficiently. It is able to intelligently manage journey risk and reliability of travel options by pre-computing alternative routes-to-destination from each interchange point. Location awareness enables Ichibi to provide correct and up-to-date travel planning wherever you are on the planet. Available in both free and paid versions, Ichibi is the perfect companion for any traveller.

The *free* version offers no booking options and supports individual travel options only. The *paid* version adds multi-modal booking options, information on user reputation, and the ability to coordinate with other travellers. Both versions support data privacy and location cloaking by default and multi-device synchronisation.

In the following, we discuss pre-trip and en-route support prototypically. We also propose an overview of the corresponding architecture. In this context, we assume that services such as route planning, transport booking, etc. are available; that we have perfect positioning functionality and internet connectivity; that adequate transport network information (timetables, delays, arrival time, etc.) and real-time data (either from transport operators or crowd-sourced from the app) is available; that there is adequate cloud storage on a central server; that the app is designed following the privacy-by-design by design principle.

Pre-trip functionality. Planning of multi-modal travel options is supported as follows. Before Ichibi can be used for travel planning, the traveler has to provide a minimum amount of personal data as well as her travel preferences such as prefered modes, personal risk aversity and the importance of typical travel objectives such as overall travel time, maximum number of transfers, importance of travel costs etc. For a particular trip, information on origin and destination, date, whether it is a return trip or not as well as well as the underlying trip profile (business, leisure, etc.) have to be specified. According to the given information, Ichibi combines information on available services and their expected service quality. As a result, the traveler can choose from a set of different options and book her tickets subsequently. The app informs the traveler if any disruptions occur at any point.

En-Route functionality. Assistance while being en-route is provided as follows. The traveler logs in for a particular trip. If any disruptions become known, the traveler is alerted, especially when delays or disruptions might impact the rest of the journey. In case of severe disruption, Ichibi would provide alternative travel options that the traveler can select. If the traveler switches to an alternative option, detailed information and assistance for the revised trip are provided, and tickets are booked if necessary. After the trip, the user is asked to evaluate the assistance functionality and her individual travel experience. This information can be used to automatically refine the traveler's preferences.

Architecture. Ichibi is built on a cloud solution that integrates the multitude of available travel options and services. The central server provides middleware functionality integrating information on flights, the road network, train services, availability of car sharing services, and related services such as weather forecasts. There are powerful planning, querying and filtering components that are able to determine the best travel options from the multitude of above services. A particular focus of Ichibi is on the assessment of a travel option's reliability and the adherence to buffers that correspond to the risk aversity of the particular traveler and the expected reliability of the (combined) travel options. User preferences and user travel experiences are stored in a secured travel database and revealed to the Ichibi server if approved by the particular traveler.

Added value. The Ichibi travel app is a combination of pre-trip travel planning and on-trip travel assistance. It offers complete booking of multi-mode travel options, information on risks for specific connections, trip coordination with others and timely detection of disruptions.

5.4 Multimodal Pre-trip Planner

Bo Xu, Dirk Mattfeld, and Benjamin Kickhöfer

Motivation. Pre-trip planners are information systems that plan transportation modes, routes, inter-modal transitions for user specified source and destination(s). Typical pre-trip planners for the train/bus mode are based on schedules; typical pre-trip planners for the car mode are based on average travel times and current traffic conditions. These planners do not take into considerations the reliability of travel time of a route. However, there are situations in which the reliability of travel time is important for trip planning. For example, when a traveler needs to catch a flight, the traveler may sacrifice the length of travel time for the predictability of travel time. We propose an application called "Multimodal Pre-trip Planner" to enable pre-trip planning with travel time reliability taken into account.

The Application. The proposed application combines historical data from various sources (web, mobile phones, sensors, ...) in order to provide pre-trip information on an O-D level. The pre-trip information includes the average travel time and reliability (e.g., standard deviation of travel time) for an arbitrary O-D pair. For the train/bus mode it also includes the price for arbitrary time bins of departure. For example, for a trip from Dagstuhl to Frankfurt Airport, the application may provide information such as the following. If departing at 7am, for the car mode, the average travel time is 2 hours, the standard deviation is 20 minutes, and with 85% probability the delay is less than 10 minutes; for the train mode, the average travel time is 3 hours, the standard deviation is 1 minute, and with 98% probability the delay is less than 10 minutes; and so on. Similarly for the departure time of 8am, 9am, etc. In this way the application creates a data cube that can be viewed from different perspectives in terms of departing time, transportation mode, etc.

Architecture and Challenges. The input of the Multimodal Pre-trip Planner is recorded historical travel-time data and real-time travel-time data. For the train mode the input data is on O-D basis. This is because the travel-time collected for the train mode is usually per O-D pair. For the car mode the input data is on link basis. This is because existing traffic monitoring approaches, such as loop sensors or floating car data, usually generate travel time per road-segment. By combining the historical travel-time data and real-time travel-time data, the application computes travel time reliability on O-D basis for the train/bus mode and on link basis for the car mode. The application then aggregates link reliability to get O-D level reliability for the car mode. The data cube is updated accordingly. The data cube can be updated on a daily basis.

One challenge is the integration of data from different sources. Another challenge is aggregation from link-based reliability to O-D based reliability.

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